ECONOMIC AND SOCIAL COMMISSION
FOR ASIA AND THE PACIFIC
AND
WORLD METEOROLOGICAL ORGANIZATION

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Typhoon Committee
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29 January to 1 February 2013
Hong Kong, China

REPORT ON AMENDMENTS TO THE TYPHOON COMMITTEE OPERATIONAL MANUAL

(Item 6.2 of the Provisional Agenda)

Submitted by the Rapporteur

Introduction

1. The Typhoon Committee Operational Manual - Meteorological Component (TOM) has been reviewed and updated every year since its first issue in 1987. The 2011 edition was completed and posted on the WMO website in March 2011 in accordance with the approval of amendments to the 2010 edition by the 44th session of the Typhoon Committee (06 to 11 February 2012 Hangzhou, China).

2. At the 44th session, the Committee decided that the rapporteur of the Japan Meteorological Agency (JMA) would continue arrangements for updating the TOM. In this connection, on 28 September 2012, the rapporteur, Mr Masashi Kunitsugu, Head of the JMA National Typhoon Center invited the focal points of the meteorological component of the Members to provide proposals for updates to the TOM.

3. As of the end of January 2013, proposals for updates to the TOM had been submitted by the two focal points of Japan and Thailand.

4. Proposed amendments to the TOM are attached as Annex 1 and 2, and given below are the major points of the amendments:

- Update of meaning of terms used for regional exchange related to extra-tropical cyclone and tropical cyclone crossing, landfall and impact (Chapter 1)
- Inclusion of information on plans to launch Himawari-8 (Chapter 2)
- Update of information on storm surge model products and inclusion of information on SATAID service (Chapter 3)
- Update of information on telecommunication network (Chapter 5)
- Update of technical specifications of radars in Japan (Appendix 2-D)
- Update of outline of RSMC Tokyo tropical cyclone prediction models (Appendix 3-A)
- Inclusion of information on satellite-based analysis used by the RSMC Tokyo, CMA, HKO and U. S. Joint Typhoon Warning Center (JTWC) (Appendix 3-C Annex 1-5)

Action Proposed

5. The Committee is invited to review and approve the proposed amendments to the TOM attached as Annex 1 and 2 with necessary modifications.

Annex 1

Draft Amendments to
the Typhoon Committee Operational Manual – Meteorological Component (TOM)
proposed by the Members

Page	Line	Present Description	Proposed Amendment
Chapter 1.3			
3	39	Extra-tropical cyclone: Low-pressure system which develops in latitudes outside the tropics.	Extra-tropical cyclone: A former tropical cyclone that has gone through extra-tropical transition and lost its initial tropical characteristics.
4	1		*<<sentence to be inserted >>* Extra-tropical transition: is an evolutionary process by which a symmetric warm core tropical cyclone transforms to an asymmetric cold core extratropical cyclone. This process includes a change in the distribution of clouds, winds, and precipitation. Also, the primary energy source changes from latent heat release in deep convective clouds of the tropical cyclone to baroclinic conversion of available potential energy in the extratropical cyclone.
5	9		*<<sentence to be inserted >>* Tropical cyclone coastal crossing: Cyclone centre passage across the coast.
5	13		*<<sentence to be inserted >>* Tropical cyclone impact: Evidence of damage or disruption caused by tropical cyclone-generated hazard(s) either direct or indirect. (includes damaging large swells from distant tropical cyclones).
5	13		*<<sentence to be inserted >>* Tropical cyclone island crossing: Cyclone centre passage across the island.
5	13		*<<sentence to be inserted >>* Tropical cyclone landfall: refer to tropical cyclone coastal crossing.
Chapter 2.2			
8	10	Enhanced upper-air observations are carried out six-hourly when these ships are	Enhanced upper-air observations are carried out six-hourly when the vessel is
Chapter 2.4			
9	8		*<<sentence to be inserted >>* JMA plans to launch Himawari-8 in 2014 and start its operation in 2015. MTSAT-1R will be retired in 2015, and JMA will terminate the HRIT/LRIT direct dissemination service at the same time. Himawari-8 will not carry a

			direct data dissemination system, and image data from it will be available via JMA's website and other online resources. The Agency has been assessing the feasibility of data dissemination using a commercial telecommunication satellite, and tentatively plans to begin this service in 2015 in parallel with the direct dissemination of imagery from MTSAT-2 via MTSAT-1R. Further information on Himawari-8 and -9 is available at the website of Meteorological Satellite Center of JMA (http://mscweb.kishou.go.jp/himawari89/index.html).
Chapter 3.1			
11	Table 3.1		*<<to be replaced by>>* New document (see Annex 1-1)
13	Table 3.2		*<<to be replaced by>>* New document (see Annex 1-2)
14	Table 3.3		*<<to be replaced by>>* New document (see Annex 1-3)
Chapter 5.4			
20	Figure 5.1		Bangkok – Hong Kong circuit is added.
21	Table 5.1 14	*<<Telecommunication>>* Bangkok - Beijing Cable (IPLC), 64 kbps, FTP protocol	Bangkok - Beijing 64 kbps leased line
21	Table 5.1 15	Bangkok - Hanoi Cable (IPLC), 64 kbps, FTP protocol	Bangkok - Hanoi 64 kbps leased line
21	Table 5.1 16		*<<sentence to be inserted >>* Bangkok – Hong Kong Internet
22	Table 5.1 2	Bangkok - Kuala Lumpur Cable (IP-VPN), 64 kbps, socket	Bangkok - Kuala Lumpur 64 kbps leased line
22	Table 5.1 3	Bangkok - Singapore Cable (IP-VPN), 64 kbps, socket Washington 1 Mbps/Tokyo 3 Mbps	Bangkok - Singapore 64 kbps leased line
Appendix 2-D			
42		*<<Technical Specifications of Radars of Japan>>*	*<<to be replaced by>>* New document (see Annex 1-4)
Appendix 3-A			
73		*<<Outline of RSMC Tokyo - Tropical Cyclone Prediction Models>>*	*<<to be replaced by>>* New document (see Annex 1-5)
Appendix 3-C,		Annex 1-5	
115		*<<The Tropical Cyclone Analysis and Forecasting Technique Using Satellite Data>>*	*<<to be replaced by>>* New document (see Annex 1-6)
		<<The Tropical Cyclone Analysis and Forecasting Technique Using Satellite Data>>	*<<to be linked to the WMO TCP website>>* New document (see Annex 2-1, 2-2, 2-3, 2-4)
Appendix 5-A			
155-157		*<<List of Addresses, Telex/Cable and Telephone Numbers of the Tropical Cyclone Warning Centers in the Region>>*	*<<to be replaced by>>* New document (see Annex 1-7)

Table 3.1 Chart-form products provided by RSMC Tokyo - Typhoon Center for regional purposes

Model	Area	Contents and Level	Forecast hours	Initial time	Availability
Global Analysis/ Forecast Models	A' (Far East)	500hPa (Z, ζ)	Analysis	00, 12UTC	GTS
			24, 36	00, 12UTC	GTS, JMH
		500hPa (T), 700hPa (D)	24, 36	00, 12UTC	GTS, JMH
		700hPa (ω), 850hPa (T, A)	Analysis	00, 12UTC	GTS
			24, 36	00, 12UTC	GTS, JMH
		Surface (P, R, A)	24, 36	00, 12UTC	GTS, JMH
	C (East Asia)	300hPa (Z, T, W, A)	Analysis	00UTC	GTS
		500hPa (Z, T, A)	Analysis	00, 12UTC	GTS, JMH
		500hPa (Z, ζ)	48, 72	00, 12UTC	GTS
		700hPa (Z, T, D, A)	Analysis	00, 12UTC	GTS
		700hPa (ω), 850hPa (T, A)	48, 72	12UTC	GTS
		850hPa (Z, T, D, A)	Analysis	00, 12UTC	GTS, JMH
		Surface (P, R)	24, 48, 72	00, 12UTC	GTS, JMH
			96, 120	12UTC	JMH
	O (Asia)	500hPa (Z, ζ)	96, 120, 144, 168, 192	12UTC	GTS
		850hPa (T), Surface (P)			
	Q (Asia Pacific)	200hPa (Z, T, W), Tropopause (Z)	Analysis	00, 12UTC	GTS
		250hPa (Z, T, W)	Analysis, 24	00, 12UTC	
		500hPa (Z, T, W)		00, 12UTC	
	D (N.H.)	500hPa (Z, T)	Analysis	12UTC	GTS
	W (NW Pacific)	200hPa (streamline)	Analysis, 24, 48	00, 12UTC	GTS
		850hPa (streamline)		00, 12UTC	
JCDAS	D' (N.H.)	100hPa (Z, Z anomaly to climatology)	5-day average of analysis	00UTC	GTS
		500hPa (Z, Z anomaly to climatology)			
Ocean Wave	C'' (NW Pacific)	Surface (height, period and direction)	12, 24, 48, 72	00, 12UTC	GTS, JMH
SST	C	Sea Surface Temperature	Daily analysis	-	JMH

Notes:

(a) Area

A', C, O, Q, D, W, D' and C'' are illustrated in Figure 3.1.

(b) Contents

Z: geopotential height ζ: vorticity T: temperature

D: dewpoint depression ω: vertical velocity W: wind speed by isotach

A: wind arrows P: sea level pressure R: rainfall

Table 3.2 NWP products (GSM and EPS) provided by RSMC Tokyo - Typhoon Center
(Available at http://www.wis-jma.go.jp/cms/)

Model	GSM	GSM	GSM
Area and resolution	Whole globe, 1.25°×1.25°	20°S–60°N, 60°E–160°W 1.25°×1.25°	Whole globe, 2.5°×2.5°
Levels and elements	10 hPa: Z, U, V, T 20 hPa: Z, U, V, T 30 hPa: Z, U, V, T 50 hPa: Z, U, V, T 70 hPa: Z, U, V, T 100 hPa: Z, U, V, T 150 hPa: Z, U, V, T 200 hPa: Z, U, V, T, ψ, χ 250 hPa: Z, U, V, T 300 hPa: Z, U, V, T, H, ω 400 hPa: Z, U, V, T, H, ω 500 hPa: Z, U, V, T, H, ω, ζ 600 hPa: Z, U, V, T, H, ω 700 hPa: Z, U, V, T, H, ω 850 hPa: Z, U, V, T, H, ω, ψ, χ 925 hPa: Z, U, V, T, H, ω 1000 hPa: Z, U, V, T, H, ω Surface: P, U, V, T, H, R†	10 hPa: Z, U, V, T 20 hPa: Z, U, V, T 30 hPa: Z, U, V, T 50 hPa: Z, U, V, T 70 hPa: Z, U, V, T 100 hPa: Z, U, V, T 150 hPa: Z, U, V, T 200 hPa: Z§, U§, V§, T§, ψ, χ 250 hPa: Z, U, V, T 300 hPa: Z, U, V, T, D 400 hPa: Z, U, V, T, D 500 hPa: Z§, U§, V§, T§, D§, ζ 700 hPa: Z§, U§, V§, T§, D§, ω 850 hPa: Z§, U§, V§, T§, D§, ω, ψ, χ 925 hPa: Z, U, V, T, D, ω 1000 hPa: Z, U, V, T, D Surface: P¶, U¶, V¶, T¶, D¶, R¶	10 hPa: Z*, U*, V*, T* 20 hPa: Z*, U*, V*, T* 30 hPa: Z°, U°, V°, T° 50 hPa: Z°, U°, V°, T° 70 hPa: Z°, U°, V°, T° 100 hPa: Z°, U°, V°, T° 150 hPa: Z*, U*, V*, T* 200 hPa: Z, U, V, T 250 hPa: Z°, U°, V°, T° 300 hPa: Z, U, V, T, D*‡ 400 hPa: Z*, U*, V*, T*, D*‡ 500 hPa: Z, U, V, T, D*‡ 700 hPa: Z, U, V, T, D 850 hPa: Z, U, V, T, D 1000 hPa: Z, U*, V*, T*, D*‡ Surface: P, U, V, T, D‡, R†
Forecast hours	0–84 every 6 hours and 96–192 every 12 hours † Except analysis	0–84 (every 6 hours) § 96–192 (every 24 hours) for 12UTC initial ¶ 90–192 (every 6 hours) for 12UTC initial	0–72 every 24 hours and 96–192 every 24 hours for 12UTC ° 0–120 for 12UTC † Except analysis * Analysis only
Initial times	00, 06, 12, 18UTC	00, 06, 12, 18UTC	00UTC and 12UTC ‡ 00UTC only

Model	Mid-range EPS
Area and resolution	Whole globe, 2.5°×2.5°
Levels and elements	250 hPa: μU, σU, μV, σV 500 hPa: μZ, σZ 850 hPa: μU, σU, μV, σV, μT, σT 1000 hPa: μZ, σZ Surface: μP, σP
Forecast hours	0–192 every 12 hours
Initial times	12UTC

Model	GSM	GSM
Area and resolution	5S-90N and 30E-165W, Whole globe 0.25° × 0.25°	5S-90N and 30E-165W, Whole globe 0.5° × 0.5°
Levels and elements	Surface: U, V, T, H, P, Ps, R, Cla, Clh, Clm, Cll	10 hPa: Z, U, V, T, H, ω 20 hPa: Z, U, V, T, H, ω 30 hPa: Z, U, V, T, H, ω 50 hPa: Z, U, V, T, H, ω 70 hPa: Z, U, V, T, H, ω 100 hPa: Z, U, V, T, H, ω 150 hPa: Z, U, V, T, H, ω 200 hPa: Z, U, V, T, H, ω, ψ, χ 250 hPa: Z, U, V, T, H, ω 300 hPa: Z, U, V, T, H, ω 400 hPa: Z, U, V, T, H, ω 500 hPa: Z, U, V, T, H, ω, ζ 600 hPa: Z, U, V, T, H, ω 700 hPa: Z, U, V, T, H, ω 800 hPa: Z, U, V, T, H, ω 850 hPa: Z, U, V, T, H, ω, ψ, χ 900 hPa: Z, U, V, T, H, ω 925 hPa: Z, U, V, T, H, ω 950 hPa: Z, U, V, T, H, ω 975 hPa: Z, U, V, T, H, ω 1000 hPa: Z, U, V, T, H, ω Surface: U, V, T, H, P, Ps, R, Cla, Clh, Clm, Cll
Forecast hours	0– 84 (every 6 hours) and 90–216 (every 24 hours) are also available for 12 UTC Initial time.	0– 84 (every 6 hours) and 90–216 (every 24 hours) are also available for 12 UTC Initial time.
Initial times	00, 06, 12, 18 UTC	00, 06, 12, 18 UTC

Notes: Z: geopotential height U: eastward wind V: northward wind
T: temperature D: dewpoint depression H: relative humidity
ω: vertical velocity ζ: vorticity ψ: stream function
χ: velocity potential P: sea level pressure Ps: pressure
R: rainfall Cla: total cloudiness Clh: cloudiness (upper layer)
Clm: cloudiness (middle layer) Cll: cloudiness (lower layer)

The prefixes μ and σ represent the average and standard deviation of ensemble prediction results respectively.
The symbols °, *, ¶, §, ‡ and † indicate limitations on forecast hours or initial time as shown in the tables.

Table 3.3 List of other products provided by RSMC Tokyo - Typhoon Center
(Available at http://www.wis-jma.go.jp/cms/)

Data	Contents / frequency (initial time)
Satellite products	High density atmospheric motion vectors (BUFR) (a) MTSAT-2 (VIS, IR, WV), 60S-60N, 90E-170W VIS: every hour (00-09, 21-23 UTC), IR and WV: every hour (b) METEOSAT-7 (VIS, IR, WV) VIS: every 1.5 hours between 0130 and 1500 UTC IR and WV: every 1.5 hours Clear Sky Radiance (CSR) data (BUFR) MTSAT-2 (IR, WV) radiances and brightness temperatures averaged over cloud-free pixels: every hour
Tropical cyclone Information	Tropical cyclone related information (BUFR) • tropical cyclone analysis data (00, 06, 12 and 18 UTC)
Wave data	Global Wave Model (GRIB2) • significant wave height • prevailing wave period • wave direction Forecast hours: 0–84 every 6 hours (00, 06 and 18UTC) 0–84 every 6 hours and 96-192 every 12 hours (12 UTC)
Observational data	(a) Surface data (TAC/TDCF) SYNOP, SHIP, BUOY: Mostly 4 times a day (b) Upper-air data (TAC/TDCF) TEMP (parts A-D), PILOT (parts A-D) Mostly twice a day
Storm surge	Storm surge model for Asian area • storm surge distribution (map image) • time series charts (at requested locations) The plotted values are storm surges, predicted water levels, astronomical tides, surface winds, and sea level pressures. Forecast hours: 0–72 every 3 hours (00, 06 12, and 18UTC) Only in the case of a tropical cyclone being in the forecast time (Available at https://tynwp-web.kishou.go.jp/)
SATAID service	(a) Satellite imagery (SATAID) MTSAT (b) Observation data (SATAID) SYNOP, SHIP, METAR, TEMP (A, B) and ASCAT sea-surface wind (c) NWP products (SATAID) GSM (Available at http://www.wis-jma.go.jp/cms/sataid/)

Name of the Member **Japan - 1**

NAME OF STATION		Sapporo /Kenashiyama	Kushiro /Kombumori	Hakodate /Yokotsudake	Sendai	Akita
SPECIFICATIONS	Unit					
Index number		47415	47419	47432	47590	47582
Location of station		43° 08′ N 141° 01′ E	42° 58′ N 144° 31′ E	41° 56′ N 140° 47′ E	38° 16′ N 140° 54′ E	39° 43′ N 140° 06′E
Antenna elevation	m	749.0	121.5	1141.7	98.2	55.3
Wave length	cm	5.61	5.61	5.59	5.61	5.59
Peak power of transmitter	kW	250	250	250	250	250
Pulse length	μ s	1.1/2.6	1.1/2.6	1.1/2.6	1.0/2.6	1.1/2.6
Sensitivity minimum of receiver	dBm	-109/-112	-110/-113	-108/-111	-108/-111	-108/-112
Beam width (Width of over -3dB antenna gain of maximum)	deg	1.1(H) 1.1(V)	1.1(H) 1.0(V)	1.0(H) 1.0(V)	1.0(H) 1.0(V)	1.0 (H) 0.9 (V)
Detection range	km	400	400	400	400	400
Scan mode in observation 1.Fixed elevation 2.CAPPI 3.Manually controlled		2	2	2	2	2
DATA PROCESSING						
MTI processing 1.Yes, 2.No		1	1	1	1	1
Doppler processing 1.Yes, 2.No		1	1	1	1	1
Display 1.Digital, 2.Analog		1	1	1	1	1
OPERATION MODE (When tropical cyclone is within range of detection) 1.Hourly 2.3-hourly 3.Others		1	1	1	1	1
PRESENT STATUS 1.Operational 2.Not operational (for research etc.)		1	1	1	1	1

OUTLINE OF RSMC TOKYO - TROPICAL CYCLONE PREDICTION MODELS

(a) Global Spectral Model (GSM-1110)

Data Assimilation:
- Four-dimensional variational (4D-Var) data assimilation method with 6-hours assimilation window using 3 to 9-hours forecast by GSM as first-guess field
- Data cut-off at 2.3 hours from synoptic time for prediction model, at 7.8 ~ 11.8 hours from synoptic time for assimilation cycle
- Dynamic quality control considering temporal and spatial variabilities
- Reduced Gaussian grid, roughly equivalent to 0.1875° x 0.1875° in latitude and longitude
- Model p-sigma hybrid levels (60) + surface (1)

(bogusing of tropical cyclones)
- Axis-symmetric structure based on Frank's (1977) empirical formula with parameters prescribed on forecasters' analysis mainly applying the Dvorak method to MTSAT imagery
- Asymmetric structure derived from first-guess field (prediction using GSM)
- Bogus structure is given as pseudo-observation data to the analysis for the prediction model

Operation:
(schedule)
Four times a day (0000, 0600, 1200 and 1800 UTC)
(integration time)
84 hours from 0000, 0600 and 1800 UTC, and 216 hours from 1200 UTC

Prediction model:
(dynamics)
- Hydrostatic, primitive, semi-Lagrangian-form equations
- Semi-implicit time integration
- TL959 spectral discretization in the horizontal direction
- Reduced Gaussian grid, roughly equivalent to 0.1875° x 0.1875° in latitude and longitude (~20km grid)
- Finite differencing on 60 p-sigma hybrid levels in the vertical direction
- Horizontal diffusion by linear second-order Laplacian

(physics)
- Arakawa-Schubert (1974) cumulus parameterization with modifications by Moorthi and Suarez (1992), Randall and Pan (1993) and Kuma and Cho (1994)
- Prognostic cloud water scheme by Smith (1990)
- Bulk formulae for surface fluxes with similarity functions by Louis (1982)
- Vertical diffusion with the level-2 closure model by Mellor and Yamada (1974) with moist effect included
- Gravity wave drag by Palmer et al. (1986) and Iwasaki et al. (1989)
- Simple Biosphere Model (SiB) by Sellers et al. (1986) and Sato et al. (1989a,b)

Boundary conditions:
(SST)
0.25° x 0.25° daily analysis with climatic seasonal trend

(b) Typhoon Ensemble Prediction System (TEPS)

Initial condition:

Interpolation of the initial condition for GSM plus ensemble perturbations

Methods to make ensemble perturbations:

- Singular vector (SV) method to generate initial perturbations
  - Linearized model and its adjoint version based on those adopted in 4-D variational calculus, which consist of full dynamics of Eulerian integrations and full physical processes containing representations of surface fluxes, vertical diffusion, gravity wave drag, large-scale condensation, long-wave radiation and deep cumulus convection
  - T63 (~180 km grid) spectral discretization in the horizontal direction
  - Finite differencing on 40 p-sigma hybrid levels in the vertical direction
  - Two types of SV spatial area (fixed as the Northwestern Pacific and movable as within a 750-km-radius of the predicted TC's position in one-day forecasting) introduced
- A stochastic physics scheme to represent model uncertainties
  - Perturbed parameterized tendencies of u, v, T and q

Ensemble size:

11

Operation:

(schedule)

Four times a day (0000, 0600, 1200 and 1800 UTC)

(tropical cyclone conditions that can trigger model prediction)

- a tropical cyclone of TS intensity or higher exists in the area of responsibility (0°N - 60°N, 100°E - 180°E)
- a tropical cyclone is expected to reach TS intensity or higher in the area within the next 24 hours
- a tropical cyclone of TS intensity or higher is expected to move into the area within the next 24 hours

(maximum number of predictions)

Three for each synoptic time (0000, 0600, 1200 and 1800 UTC)

(integration time)

132 hours

(domain)

globe

(Prediction model)

- Lower-resolution version of the GSM
- TL319 spectral discretization in the horizontal direction
- Reduced Gaussian grid, roughly equivalent to 0.5625° x 0.5625° in latitude and longitude (~55km grid)
- Finite differencing on 60 p-sigma hybrid levels in the vertical direction

THE TROPICAL CYCLONE ANALYSIS AND FORECASTING TECHNIQUE USING SATELLITE DATA

The tropical cyclone analysis and forecasting technique using satellite data developed by Vernon F. Dvorak (Dvorak, 1984) is mainly used for TC warnings. The methods are described in the Global Guide to Tropical Cyclone Forecasting at the WMO/TCP website (http://www.wmo.int/pages/prog/www/tcp/TCF/GlobalGuide.html).

Detailed operational satellite-based analysis of TCs used by the RSMC Tokyo, CMA, HKO and U. S. Joint Typhoon Warning Center (JTWC) are attached in Annex 2-5 to this Appendix.

The objective techniques developed by the TC research community, including the Advanced Dvorak Technique (ADT), the Advanced Microwave Sounding Unit method (AMSU), the Automated Rotational Center Hurricane Eye Retrieval algorithm (ARCHER), the SATellite CONsensus approach (SATCON), passive microwave (PMW) applications, and the Multiplatform TC Surface Wind Analysis (MTCSWA), are described in Appendix C of the Proceedings of the International Workshop on Satellite Analysis of Tropical Cyclones held in Honolulu, Hawaii, USA 13–16 April 2011 (http://www.wmo.int/pages/prog/www/tcp/documents/TCP-52_IWSATC_proceedings_en.pdf).

OPERATIONAL TYPHOON SATELLITE ANALYSIS USED BY METEOROLOGICAL CENTERS

Organization	Method	Detailed Description of Methods
RSMC Tokyo	Dvorak (1984), Early-stage Dvorak Analysis (Tsuchiya et al. 2001, Kishimoto 2008) for the TCs in generation stage	Annex 2 (http://www.wmo.int/pages/prog/www/tcp/operational-plans/XXXXXXX.html)
CMA	Real time analysis: Before 2012: Simplified Dvorak technique. Since 2012: Dvorak (1984). Best track analysis: 1) Mathematical morphology (TC center location) and Convective Core Extraction technique (TC intensity estimation) 2) Use of real time satellite analysis issued by various centers as reference.	Annex 3a (http://www.wmo.int/pages/prog/www/tcp/operational-plans/XXXXXXX.html) Annex 3b (http://www.wmo.int/pages/prog/www/tcp/operational-plans/XXXXXXX.html)
HKO	Dvorak (1984) ADT version 7.2.2 of McIDAS used as reference	Annex 4 (http://www.wmo.int/pages/prog/www/tcp/operational-plans/XXXXXXX.html)
JTWC	Dvorak (1984), Subtropical intensity technique (Hebert and Poteat, 1975)	Annex 5 (http://www.wmo.int/pages/prog/www/tcp/operational-plans/XXXXXXX.html)

LIST OF ADDRESSES, TELEX/CABLE AND TELEPHONE NUMBERS OF THE TROPICAL CYCLONE WARNING CENTERS IN THE REGION

Centre numbers	Mailing address	Telex/cable, Telephone, fax
Cambodia		
Attn. Mr Ly Chana Deputy Director Department of Agricultural Hydraulics and Hydrometeorology	Norodom Boulevard	Tel.: (+855) 15 913081 Fax: (+855) 23 26345
Attn. Mr Hun Kim Hak Chief of Cambodian National 66192 NMC 66191 Airport	Pochentong	Tel/Fax: (+855) 23 66193
China		
National Meteorological Center China Meteorological Adm. (Director: Jiao Meiyan)	No. 46 Zhongguancun Nandajie, Beijing 100081	Tel.: (+86) (10) 6840 6169 Cable: 2894 Fax: (+86) (10) 6217 5928 E-mail: jiaomy@cma.gov.cn
Democratic People's Republic of Korea		
Mr Ko Sang Bok Director Central Forecast Research Insitute State Hydrometeorological Adm.	Oesong-dong Central District	Telex: 38022 TCT KP Tel.: (+850) (2) 321 4539 Fax: (+850) (2) 381 4410
Hong Kong, China		
Central Forecasting Office Hong Kong Observatory (Attn. Mr. K.C. Tsui)	134A Nathan Road Tsim Sha Tsui Kowloon Hong Kong, China	Telex: 54777 GEOPH HX Tel.: (+852) 2926 8371 (Office hours) (+852) 2368 1944 (24 hours) Fax: (+852) 2721 5034 (24 hours) E-mail: kctsui@hko.gov.hk
Japan		
Forecast Division Forecast Department Japan Meteorological Agency (Director: H. Yokoyama)	1-3-4 Otemachi Chiyoda-ku Tokyo 100-8122	Telex: 2228080 METTOKJ (24 hours) Tel.: (+81) (3)3211 8303 (00 - 09 UTC on weekdays) (+81) (3) 3211 7617 (24 hours)

Fax: (+81) (3) 3211 8303

Lao People's Democratic Republic

Ministry of Agriculture and Forestry, Department of VIENTIANE Meteorology and Hydrology	P.O. Box 811 Vientiane	Telex: 4306 ONU VTELS Cable: UNDEVPRO

Macao, China

Meteorological and Geophysical Bureau (Director: Fong Soi Kun)	P.O. Box 93 Macao, China	Tel.: (+853) 88986273 Fax: (+853) 28850773 E-mail: meteo@smg.gov.mo

Malaysia

Malaysian Meteorological Dep. (Central Forecast Office, Director: Mr. Saw Bun Liong)	Jalan Sultan 46667 Petaling Jaya Selangor Malaysia	Tel.: (+60) (3) 7967 8116 (+60) (3) 7967 8119 Fax: (+60) (3) 7955 0964 E-mail: cfo@met.gov.my

Philippines

Weather Branch PAGASA (Weather Services Chief: Ellaquim A. Adug)	Asia TrustBank Bldg. 1424 Quezon Avenue Quezon City 3008	Telex: 66682 WXMLA PN Tel.: (+63) (2) 922 1996 Cable: 66682 WX MLA Fax: (+63) (2) 922 5287 (24 hours)

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OPERATIONAL TROPICAL CYCLONE ANALYSIS BY RSMC TOKYO, JAPAN

1. INTRODUCTION

The Japan Meteorological Agency (JMA) operates the RSMC Tokyo - Typhoon Center (RSMC: Regional Specialized Meteorological Center) based on a 1988 designation by the World Meteorological Organization (WMO). The Center provides information on tropical cyclones (TCs) in its area of responsibility (the western North Pacific and the South China Sea) to support disaster mitigation activities conducted by the NMHSs of ESCAP/WMO Typhoon Committee members. Such information includes the results of TC satellite image analysis issued in satellite report (SAREP) format shortly after observation times, as well as TC forecasts up to 72 hours ahead and TC track forecasts up to 120 hours ahead issued as RSMC TC advisories about 50 and 90 minutes, respectively, after observation times. Additionally, JMA provides domestic users with a variety of TC-related products such as hourly TC analysis results and 50-knot wind probability data when TCs of tropical storm (TS) intensity or higher are expected to approach Japan. All this information is based on TC analysis that has been continuously improved over more than half a century. Current operational procedures for TC analysis and related systems are outlined below, along with recent improvements and future plans for JMA.

2. OPERATIONAL PROCEDURES IN TROPICAL CYCLONE ANALYSIS

2.1 Tropical Cyclone Classification

TCs in the western North Pacific and the South China Sea are classified in the Typhoon Committee Operational Manual as follows:

Typhoon (TY):	TC with MSW of 64 knots or more
Severe tropical storm (STS):	TC with MSW between 48 and 63 knots
Tropical storm (TS):	TC with MSW between 34 and 47 knots
Tropical depression (TD):	TC with MSW of 33 knots or less

(MSW: maximum sustained winds averaged over the past 10 minutes)

To enable the provision of early warnings of TS formation, JMA analyses TDs that are expected to reach TS intensity or higher within 24 hours (ExpT) and reports the results as an RSMC Tokyo TC advisory. In addition, TDs with maximum sustained winds (MSW) between 28 and 33 knots (Beaufort scale 7) are categorized as warning-issued TDs (WTDs), and are shown in marine warnings as well as in JMA's Asia-Pacific surface analysis charts. Conversely, those with an MSW value of less than 28 knots are categorized as no-warning-issued TDs (NTDs), and are shown in JMA's Asia-Pacific surface analysis charts only. Low-pressure systems with no definite surface cyclonic wind circulation are categorized as low-pressure areas (LPAs).

2.2 Operational Tropical Cyclone Analysis

To maximize the accuracy of TC intensity analysis, meteorological data such as those from surface observations (SYNOP, SHIP and BUOY), satellite products of geostationary and polar-orbiting satellites (including scatterometer-derived wind data) and NWP (numerical weather prediction) outputs are fully utilized by JMA (Figure 1).

Figure 2 shows a timeline of JMA's operational TC analysis, which starts with satellite analysis, that is early-stage Dvorak analysis (EDA) for TCs in the generation stage or conventional Dvorak analysis for those in the developing or mature stages. After Dvorak analysis with MTSAT images for a certain observation time, comprehensive analysis using other data such as those from surface and ship observations is carried out. Through consistency checking with weather map analysis, estimated TC parameters are fixed and reported in the form of a TC advisory about 50 minutes after the observation time. Even after the issuance of a TC advisory, the TC parameters are reviewed and updated with delayed observation information such as ASCAT data until the next analysis time.

Figure 3 shows a timeline of TC post-analysis. Reanalysis is carried out with further review of Dvorak analysis considering the TC life stages overall and with all available data, including additional information received later. The TC parameters finally fixed through post-analysis are disseminated via WMO GTS as RSMC Tokyo best-track bulletins about six weeks after a TC dissipates. For TCs reaching TS intensity or higher, TC post-analysis is carried out during the period from TD formation to TD dissipation, transformation to an extratropical cyclone, or movement outside the area of responsibility. Other TDs and LPAs are also post-analyzed for the finalization of JMA's surface weather charts.

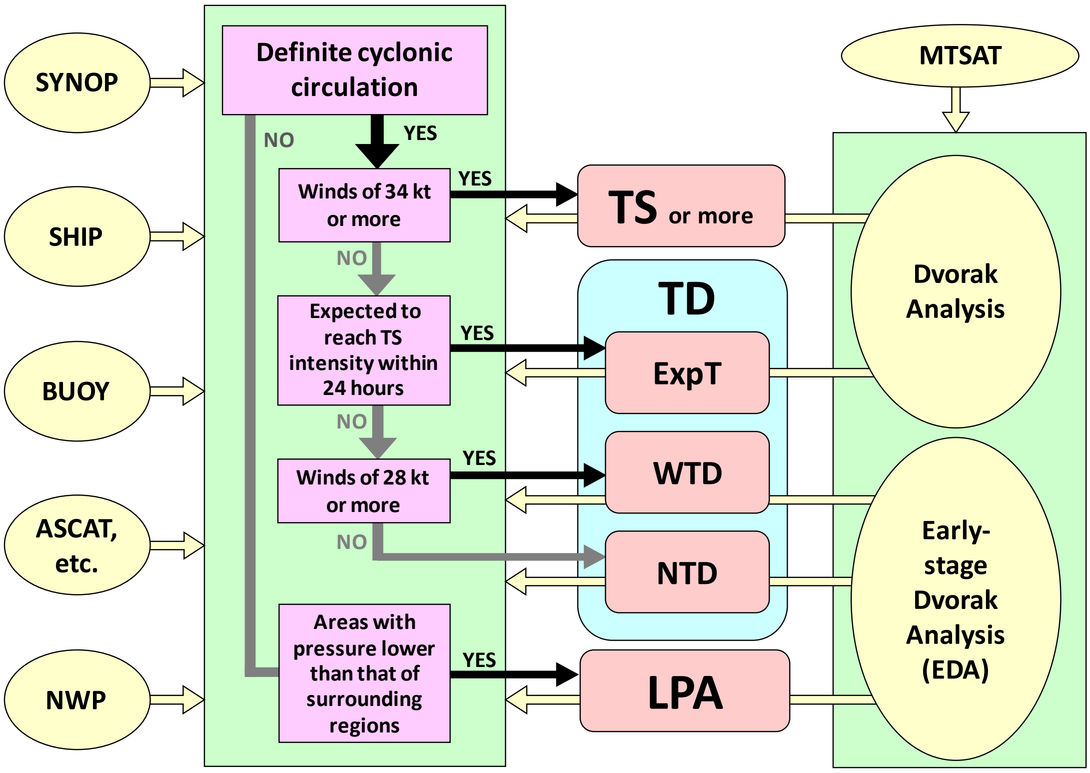


Figure 1: Flow chart of operational tropical cyclone analysis

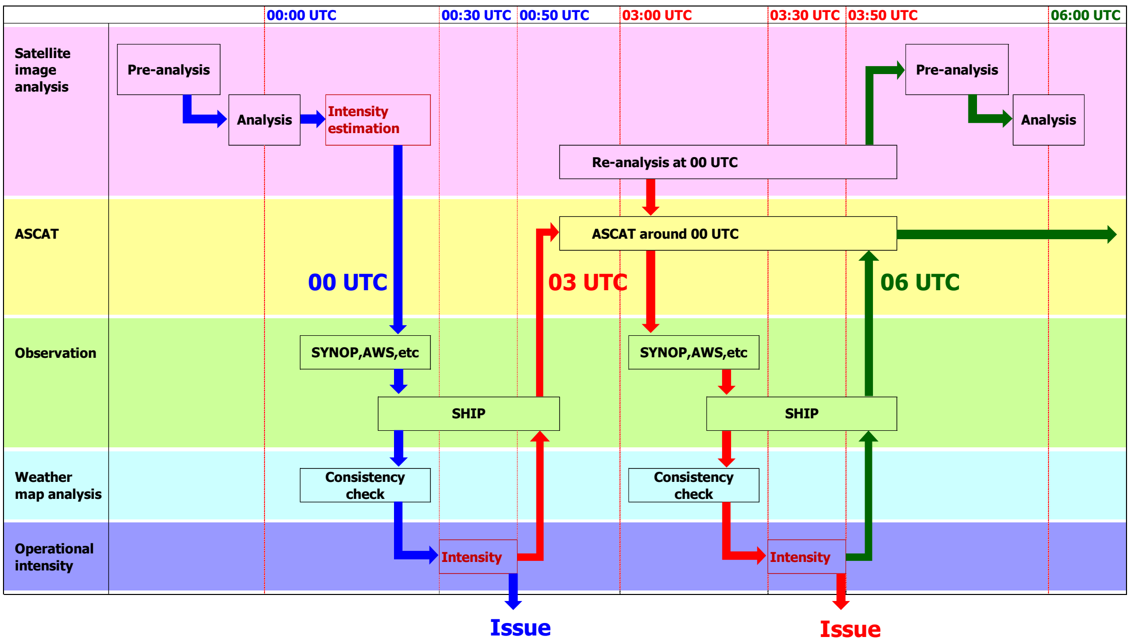


Figure 2: Timeline of operational tropical cyclone analysis

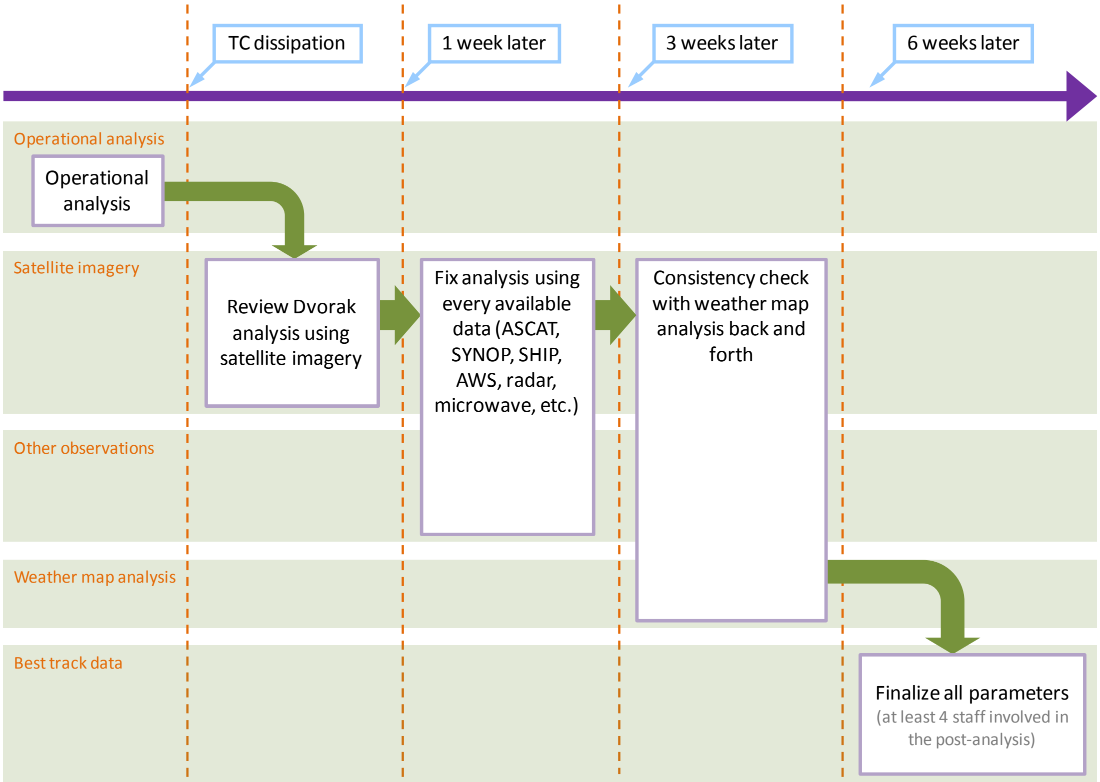


Figure 3: Timeline of tropical cyclone post-analysis

2.3 Dvorak Analysis

In 1984, JMA began operational Dvorak analysis based on Dvorak (1982) for the issuance of satellite reports (SAREPs). However, reconnaissance aircraft observations remained as the major source of data for TC intensity estimation until their termination in August 1987.

Since the introduction of the man-machine Dvorak analysis system in March 1987, the Dvorak (1984) EIR method has been adopted for JMA's operational TC intensity analysis. JMA uniquely uses a table for conversion from the Dvorak CI number to central pressure (CP) or MSW values as proposed by Koba et al. (1991) (hereafter referred to as the Koba table; Table 1), and estimation of decreasing CI numbers after landfall by Koba et al. (1989) (hereafter referred to as the landfall rule). These methods were introduced into JMA's operations after verification using JMA best-track data and CI numbers reanalyzed using the Dvorak (1984) EIR method over a period of six years during a reconnaissance period in the 1980s to maintain consistency between the periods before and after the termination of aircraft observation. The Koba table came into operation in 1989 together with the landfall rule after the introduction of a provisional table in 1987. The landfall rule, obtained from the study of 13 typhoons passing over the Philippines from 1981 to 1986, consists of the following observations:

1) When a developing TC makes landfall and the T number decreases immediately, the CI number also decreases immediately (Figure 4).
2) When a TC makes landfall within 12 hours after reaching its peak T number, and the T number continues to decrease, the corresponding CI number decreases at the same rate.
3) When a TC shows signs of redevelopment after 1) or 2) is applied, determination of the CI number follows the original Dvorak rule.

Although aircraft observation was terminated in 1987, continuous verification of the Koba table and the landfall rule have been carried out utilizing observational data for TCs passing over the Japanese islands or those from aircraft observation conducted during field experiments such as T-PARC and ITOP. Figure 5 compares CI numbers and observation data (MSLP or minimum sea level pressure and MSW observed on the islands or by aircraft) from 1995 to 2010. The results indicate good performance for the estimation of CP and MSW using the Koba table.

CI num.	MSLP(hPa)	MWS(kt)
1.0	1005	22
1.5	1002	29
2.0	998	36
2.5	993	43
3.0	987	50
3.5	981	57
4.0	973	64
4.5	965	71
5.0	956	78
5.5	947	85
6.0	937	93
6.5	926	100
7.0	914	107
7.5	901	115
8.0	888	122

Table 1: Table for conversion from CI numbers to MSLP or MSW by Koba et al. (1989). Operationally, margin for error associated with Dvorak analysis is considered.

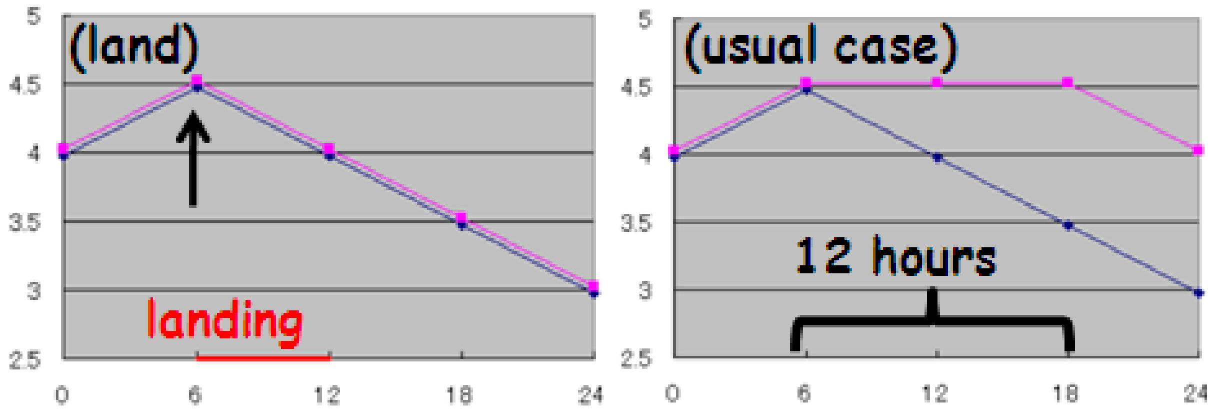


Figure 4: Example of post-landfall CI numbers (Koba et al., 1989, left).

The blue lines show T numbers and pink lines show CI numbers.

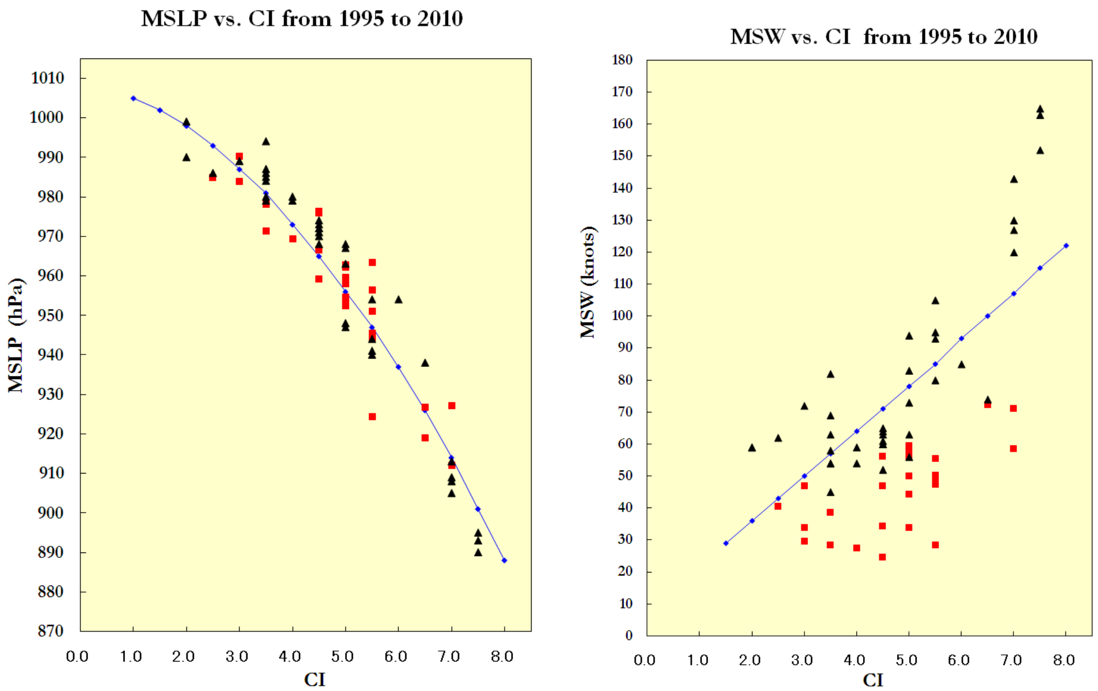


Figure 5: Verification (comparison of CI numbers and observation values)

The figures on the left and right show MSLP vs. CI and 10-minute MSW vs. CI, respectively. The red squares represent observations on the islands, and the black triangles indicate aircraft observation values recorded during T-PARC and ITOP. The blue lines show conversion using the Koba table. Note that aircraft observation values refer to minimum sea level pressures and maximum surface winds (SFMR estimations) in vortex messages.

2.4 Early-stage Dvorak Analysis (EDA)

JMA has used early-stage Dvorak analysis (EDA) operationally since 2001 to detect and classify TCs in weather map analysis and determine the likelihood of their development to TS intensity (Figure 1). EDA consists of three steps: detection of an organized convective cloud system (OCCS), classification of T numbers from 0.0 to 1.0 (T0.0/T0.5/T1.0), and classification of T1.5/T2.0 (Figure 6).

The first step of EDA is the detection of an OCCS – a convective cloud system with a cloud system center (CSC). The CSC features proposed by Tsuchiya et al. (2001) as shown in Table 2 are used for detection to supplement those of Dvorak (1984), which use animated satellite imagery.

The next step of EDA involves identifying the number of relevant features in the OCCS (Table 3). Systems with five features are classified as T1.0, those with four are classified as T0.5, and those with fewer than four are classified as T0.0 (Kishimoto 2008). After development to T1.0, OCCS classification as T1.5 or 2.0 is conducted with respect to the time variation in TC organizational factors such as the curvature and length of convective curved bands and the cyclonic rotation of convective cloud areas (Kishimoto et al. 2007). It should be noted that this classification is based on the pattern T-number (PT) chart of Dvorak (1984) to ensure continuity with the conventional Dvorak analysis in the next stage.

T numbers in EDA are set to provide criteria for TC classification indicating the likelihood of NTDs or WTDs at the time and the prospect of their development to TS intensity in the future (Kishimoto 2008). A TC in the early developing stage is first analyzed via T-number diagnosis using EDA. This analysis is followed by final TC classification using other data such as those of surface observations, ASCAT data and NWP outputs in a comprehensive manner.

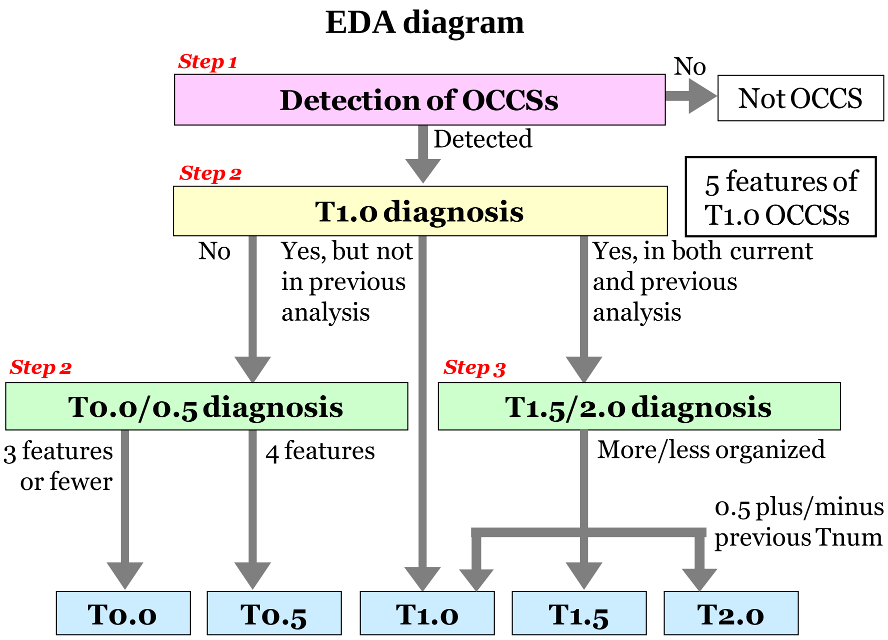


Figure 6: Outline of EDA

	Tsuchiya et al. (2001)	Dvorak (1984)
1	Curved band, a dense (-31°C or colder) overcast band that shows some curvature around a relatively warm (cloud minimum) area. It should curve at least one-fifth the distance around a 10° log spiral. Cirrus, when visible, will indicate anticyclonic shear across the expected CSC.	
2	Curved cirrus lines indicating a center of curvature within or near a dense, cold (-31°C or lower) overcast.	
3	Curved low cloud lines showing a center of curvature within 2° of a cold (-31°C or lower) cloud mass.	
4	Cumulonimbus clusters rotating cyclonically in animated imagery	None

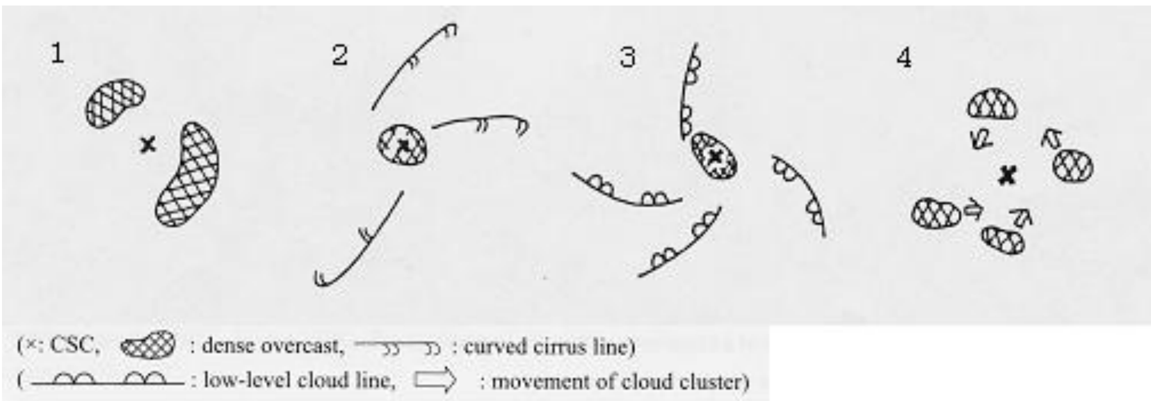


Table 2: CSC features of Tsuchiya et al. (2001) (left) and Dvorak (1984) (right). The lower figure illustrates the CSC features proposed by Tsuchiya et al.

	Tsuchiya et al. (2001)
1	A convective cloud system has persisted for 12 hours or more.
2	The cloud system has a CSC defined within a diameter of 2.5° latitude or less.
3	The CSC persists for 6 hours or more.
4	The cloud system has an area of dense, cold (-31°C or colder) overcast that appears less than 2° latitude from the center.
5	The above overcast has a diameter of more than 1.5° latitude.

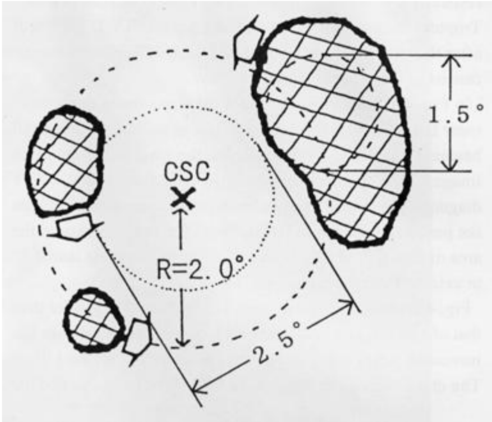


Table 3: Features of OCCSs determined as T1.0. The figure on the right shows an OCCS determined as T1.0.

2.5 Microwave Analysis

TC pattern recognition, eye analysis and measurement of eye size using Aqua/AMSR-E 89 GHz and 36 GHz channels were studied (Asano et al. 2008). Supplemental estimation of TC center positions based on this imagery is now operational, and ASCAT data have been used since 2007 to determine 30- and 50-knot radii and identify TSs (TCs with MSW values of 34 knots or more). Data with rain flags or those showing values of more than 50 knots are rejected for MSW estimation.

3. SATELLITE ANALYSIS SYSTEM

JMA has developed a system called SATAID (Satellite Animation and Interactive Diagnosis) that allows forecasters to monitor and analyse satellite images not only for daily weather analysis but also for Dvorak and EDA TC analysis. The system is equipped with a variety of functions, including the following:

1) For monitoring and analysis of observation data:

- Easy interface for TC analysis considerations such as estimation of center position, cloud system, movement and intensity (Data T number (DT)/Model Expected T number (MET)/Pattern T number (PT), final T number and CI number), and for the issuance of SAREP (Figure 7);
- Data overlays (various observations such as those made by satellite, SYNOP, SHIP, TEMP, METAR, AWS, radar, wind profiler, dropsonde, etc.) and vertical cross sections made with microwave sounders and NWP outputs to enhance understanding of TC structures;
- Support for estimation of center position and intensity using surface data from the area surrounding the TC (compass method);
- Animation to clarify the development of TCs increasing the accuracy of short-range extrapolation prediction.

2) For support of forecasts with highly functional display:

- Sequential animations and arbitrary vertical cross-section charts of NWP outputs;
- Drawing function for effective sharing of analysis and messages by forecasters.

3) For post-analysis and OJT:

- Use as a training resource with archived satellite imagery, observations and prediction data for typical weather conditions that may result in disasters.

To deal with the large amounts of data expected in the future (e.g., those from next MTSAT and various polar-orbiting satellites), a version of SATAID for a 64-bit OS (GSMLPT64) has been developed and installed. This enhanced version allows processing of greater amounts of data, thereby enabling larger areas to be displayed with a higher spatial resolution of up to 100 m as well as the superimposition and composition of multiple images using up to 16 channels.

In addition to handling geostationary satellite imagery of MTSAT VIS, IR, SP and WV, the SATAID system enables the display and overlay of other satellite data such as those from AMSR-E, SSMIS, TMI, AMSU and ASCAT of Aqua, DMSP, TRMM, NOAA and MetOp. These new data can be displayed on the SATAID screen and in operational use.

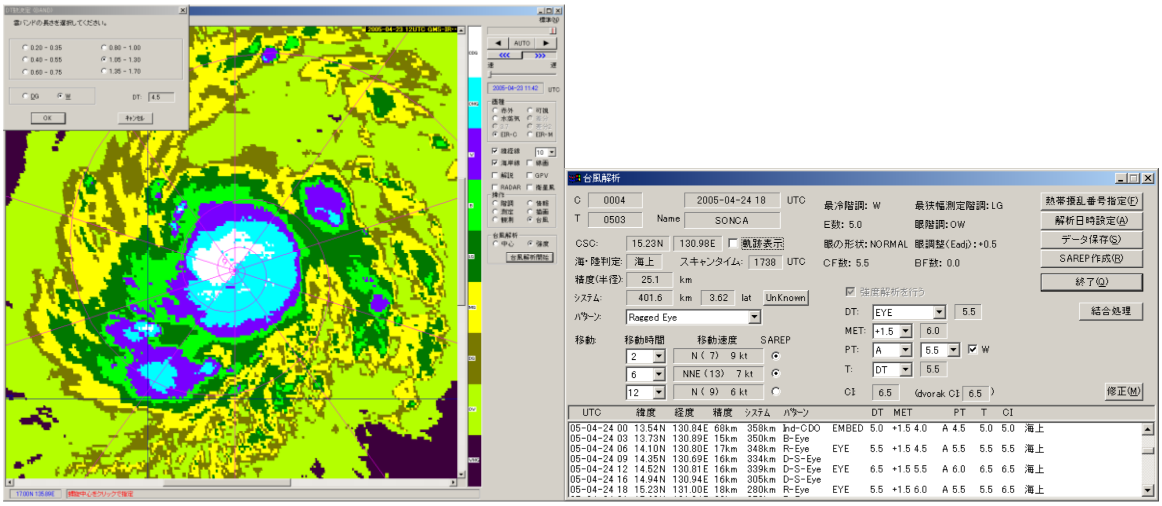


Figure 7: Example of intensity (DT number) estimation on the SATAID display.

4. FUTURE PLANS

4.1 Objective Microwave Analysis

JMA plans to introduce the elements of microwave analysis outlined below in the next few years. With manual provision of the CSC position, these estimations can be automatically executed to obtain results.

- MSW estimation using multi-channel microwave imager data based on the study of Hoshino and Nakazawa (2007) (Figure 8 (a))
- Central pressure estimation using multi-channel microwave sounder data based on the study of Bessho et al. (2010) as a method for detecting warm cores (Figure 8 (b))
- Use of the CIMSS AMSU intensity algorithm as a method for converting warm-core values to central pressure data
- Implementation of a method for estimating 30- and 50-knot radii and MSW using 7- and 10-GHz-band imagery from AMSR-E based on the study of Saitoh and Shibata (2010) (Figure 8 (c))

MSW estimation based on Hoshino and Nakazawa (2007) has been verified. The results show a close correlation with the best track data of RSMC Tokyo (Yoshida et al. 2011).

4.2 Objective Dvorak Analysis

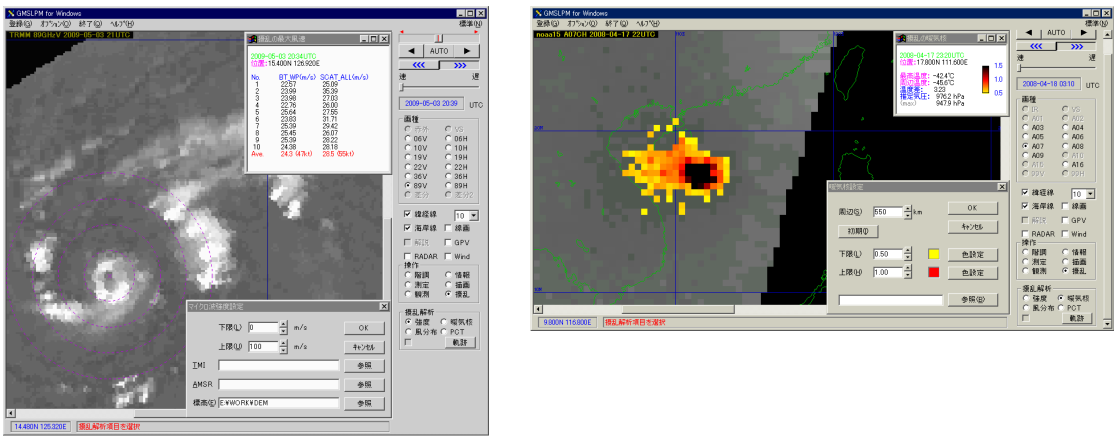
Cloud grid information objective Dvorak analysis (CLOUD) is currently being developed by JMA. The unique points of CLOUD are that it covers both EDA and Dvorak analysis and that it can be used with cloud grid information (CGI) – an objective cloud product operationally prepared by JMA since June 2005 (http://mscweb.kishou.go.jp/product/product/cgi/index.htm). CI number estimation can be automatically performed after manually fixing three parameters (CSC position, its accuracy and cloud pattern) applying the features of cumulonimbus (Cb) clusters of CGI with the extent and brightness temperature to EDA and the Dvorak rules (Figure 8 (d)). The method has been provisionally verified and shown to have a level of accuracy comparable to those of manual EDA and Dvorak analysis (Kishimoto 2011).

4.3 Objective Satellite Analysis System

JMA has installed prototypes of the above five objective methods on SATAID. These methods will become operational in 2013. Procedures in TC analysis using SATAID will be as follows:

1) Determination of CSC position, position accuracy and cloud patterns will be carried out on SATAID manually;
2) SATAID will automatically make MSW and CP estimations using CLOUD and objective microwave analysis, and will display all the results at once;
3) Considering these estimates and other observational data, forecasters will be able to determine TC intensity.

(a) (b)



(c) (d)

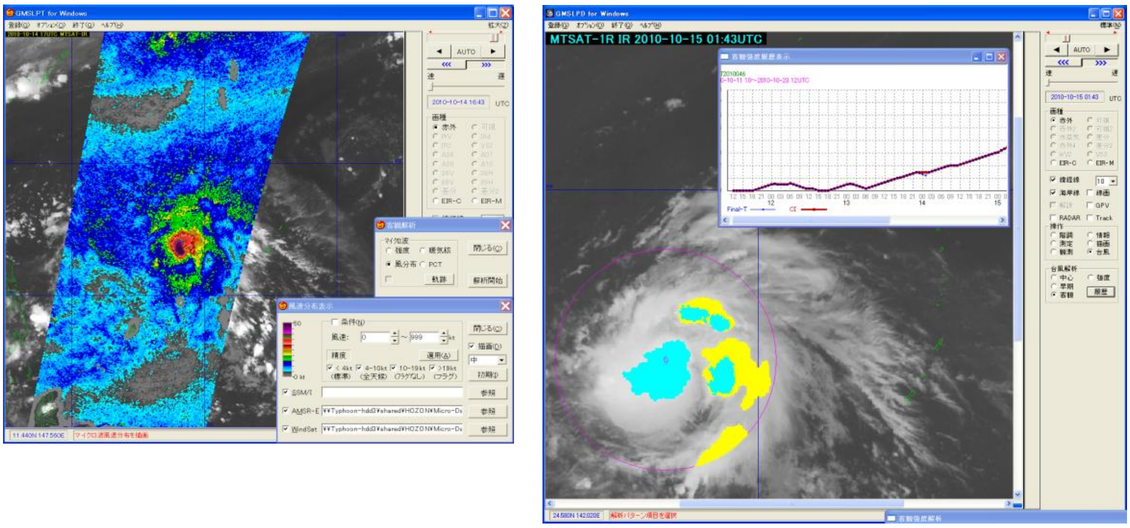


Figure 8: Examples of objective TC analysis system

(a) MSW estimation using multi-channel microwave imager data
(b) Central pressure estimation using multi-channel microwave sounder data
(c) Wind distribution estimation using 7-and 10-GHz-band data of AMSR-E
(d) Cloud grid information objective Dvorak analysis

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DVORAK PROCESS IN REAL TIME TC TRACK ANALYSIS, NMC/CMA

The National Meteorological Center of the China Meteorological Administration (NMC/CMA) adheres to the following technical guidance when performing tropical cyclone analysis (positioning and intensity estimates) since 2012:

- Tropical Cyclone Intensity Analysis Using Satellite Data, Dvorak, V. F. (NOAA Technical Report NESDIS 11 – September 1984)
- A Workbook on Tropical Clouds and Cloud Systems Observed in Satellite Imagery – Volume II – Tropical Cyclones, Dvorak, V. F. (under NOAA/NESDIS/NWS contract – September 1993)
- The Dvorak Tropical Cyclone Intensity Estimation Technique: A satellite based method that has endured for over 30 years, Velden, C. and Coauthors (Bull. Amer. Meteor. Soc., 87, 1195–1210, 2006)

The following are the NMC policies that are utilized with the above guidance:

- The NMC mainly uses the Dvorak IR analysis procedure, with VIS analysis flow sometimes used for reference.
- FY-2F, FY-2E, and MTSAT satellite images are used operationally. Daytime VIS satellite imagery of previous day may help locate the CSC (Cloud System Center) during night shifts.
- Other types of imagery and data (including microwave, radar, AScat, surface observations) and enhancements are used in finding the CSC, but are not used in intensity estimation. Search for the lowest possible center in terms of altitude (surface center if possible).
- CI (Current Intensity number) is the final output of the Dvorak technique and the estimated intensity of the cyclone. DT(Data-T number)is the estimated intensity of the cyclone based on convective cloud pattern. PT(Pattern-T number)is the intensity estimate from comparing the cyclone cloud pattern to predetermined patterns. MET(Model Expected-T number) is the intensity estimate from the past 24 hrs old FT number and a determined intensity trend. FT(Final-T number)is the intensity estimate for a given time selected from the DT, PT, or MET.
- There are six kinds of cloud patterns, curved band (VIS and IR), shear (VIS and IR), eye(VIS and IR), CDO(VIS), Embedded Center(IR), CCC(VIS and IR).
- The 10° log spiral is used for measuring curved bands. BD enhancement is applied to infrared imagery.
- Fit the spiral parallel to the inner edge of the band (VIS) or to the coldest tops in the band (IR). Measure only the primary band of the cyclone. When the band indicates two possible axes, use the axis with tighter curvature. The center of the 10° log spiral is usually not the center of the cyclone!
- For the shear pattern, measure the distance (in degrees of latitude) from the low level center to the edge of dense overcast (VIS) or to the edge of the DG shade (IR). Shear patterns tend to be rather unstable, as the convection often shows strong pulses or bursts. Therefore, the DT is often considered not to be clear cut.
- The Embedded Center pattern can only be used when the 12-hr-old FT is 3.5 or greater; otherwise, it can produce unrealistically high intensity estimates. The Embedded Center pattern is the most uncertain of all Dvorak measurements. When available and appropriate, use of VIS CDO is preferable to use of the IR embedded center.
- For the infrared eye pattern, find the coldest color on the BD enhancement that completely surrounds the eye over a width greater than the specified width. Make eye adjustment based on the color on the BD enhancement in the eye (E-Number + Eye Adjustment = CF Number). Add BF for applicable banding if CF ≥ 4 & DT < MET (CF + BF = DT). The IR Eye Pattern is the most objective of all Dvorak measurements, but it cannot produce a DT = 8.0 without adding banding.

- For small eyes (generally less than 10 nm wide), the satellite may not be able to measure the warmest temperature at the bottom of the eye. This can result in an underestimate of the intensity in both subjective and objective Dvorak techniques.
- If time permits, try multiple methods of classifying one system to see if the numbers agree (e.g. curved band and CDO or VIS and IR eyes); if they do not agree, use the number closest to the MET.
- In the Dvorak conceptual model, 'normal' strengthening or weakening is 1 T-number/day. Rapid change is 1.5 T-number/day, while slow change is 0.5 T-number/day.
- When the DT-number is well defined, the PT should be the same as the DT. During the initial development and some stages of redevelopment, CI = FT. CI is never < FT!

POLICY FOR PERFORMING DVORAK INTENSITY ESTIMATES OVER LAND

NMC will not perform Dvorak intensity estimates over large land-masses such as China's land area.

POLICY ON BREAKING CONSTRAINTS

It is sometimes necessary to break constraints to represent a rapidly developing tropical cyclone and extratropical transition. In this case, the analyst is encouraged to break constraints to provide the most accurate data possible. The analyst must give sound reasoning for breaking constraints. The analyst must also consult with the chief forecaster of NMC prior to changing the current Final-T by two T-numbers or more.

SATELLITE IMAGERY ANALYSIS IN TC BEST TRACK ANALYSIS, STI/CMA

The Shanghai Typhoon Institute of the China Meteorological Administration (STI/CMA) adheres to the following technical guidance when performing the satellite imagery analysis on tropical cyclone (TC) location and intensity, which will be used in final analysis of the TC best track since 2012:

- Center locating for non-eye typhoon based on satellite cloud image (Liu et al., 2003).
- To improve the objective position precision of TC with GIS (Lu et al., 2005).
- The convective core extraction technique for tropical cyclone intensity estimation (Lu et al., 2012).

The following are the CMA policies that are utilized with the above guidance for satellite imagery analysis:

CENTER LOCATION:

- **Mathematical morphology will be performed for non-eye TC over the sea**

For TCs without a clear eye lying over the ocean, mathematical morphology is used to find the TC center.

In determining the final best track data, the result based on the mathematical morphology is used as reference together with the TC locations reported by other operational centers.

- **Policy for TC with a clear eye over the sea**

The TC center will be located by subjective analysis based on satellite imagery.

- **Policy for TC over land or offshore area**

TC center location depends mainly on radar and surface observations. Satellite images are used as references only when either the TC center or TC circulation is clear in the satellite images.

INTENSITY ESTIMATION:

- **Policy for TC intensity estimation over the sea**

For TCs over the open ocean, the convective cores extraction technique is used for intensity estimation. The technique is objective and based on the statistical relationship between the number and intensity of convective cores on IR imageries and TC intensity.

In final best track analyses, the result of the convective cores extraction technique is used as one of the references together with TC intensities estimated by operational centers in real time.

- **Policy for TC over land or offshore area**

TC intensity is determined mainly from radar and surface observations rather than satellite imagery.

References:

Satellite Imagery Analysis Group, 1980a: Methods for typhoon prediction using the satellite imagery (I). Meteorol. Mon., 6(9), 24–26. (in Chinese)

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Lu, X. and X. Lei, 2005: To improve the objective position precision of TC with GIS. Journal of Applied Meteorological Science. 16(6): 841–848. (in Chinese)

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OPERATIONAL PROCEDURES OF TC SATELLITE ANALYSIS
AT HONG KONG OBSERVATORY

1. INTRODUCTION

The Hong Kong Observatory (HKO) has long been using manual Dvorak analysis (1984) on satellite imagery for operational estimation of the intensity of tropical cyclones (TCs). Once a potential TC is suspected to soon form, a Dvorak analysis will be performed as often as deemed appropriate for assessing the current intensity of the TC. For TCs within 0-36 N, 100-140 E, Dvorak analysis will be performed at least for 00, 06, 12 and 18 UTC imageries. For TCs within the HKO area of responsibility (viz. 10-30 N, 105-125 E), additional analysis will be performed for 03, 09, 15 and 21 UTC imageries. Operational position and intensity are provided in Hong Kong Tropical Cyclone Warning for Shipping and local tropical cyclone warnings for the public.

A post-season reanalysis of storms is carried out and the information is incorporated into the TC best track dataset. HKO's best track records started as early as 1884, but more complete records were kept since 1961. HKO produces best tracks for TCs within 0-45 N, 100-160 E until 1960 and 0-45 N, 100-180 E from 1961 onward. The maximum 10-minute surface mean wind and the minimum pressure of TCs are given in the best track dataset at 6-hourly intervals.

2. LOCAL VARIATIONS TO DVORAK (1984)

The Enhanced IR Dvorak technique has been in use operationally in HKO since early 1980s. Prior to that, the Dvorak analysis was initially carried out using the visible imageries. For reporting and warning purposes, a conversion factor of 0.9 was adopted in Hong Kong to convert 1-minute mean winds from the Dvorak wind table into 10-minute mean winds.

While there is no formal reference in the Dvorak technique about its application to TCs making landfall, Dvorak analysis is being applied in Hong Kong to TCs over the sea as well as over land.

Currently, no Dvorak analysis will be performed after a TC has transitioned into an extratropical low. Extratropical systems are not included in the HKO best tracks.

3. UNIFORMITY IN APPLICATION OF DVORAK TECHNIQUE

The HKO forecasters will carry out Dvorak analysis and fill in the tropical cyclone analysis worksheet as described in the appendix of Dvorak (1984) during operation but the information such as the current intensity (CI) or T-numbers are not being reported outside of HKO and digitized.

According to Step 9 in Dvorak (1984), the CI is to be held constant for 12 hours during the initial weakening of a TC. Normally, the HKO forecasters follow this weakening rule even when the TC has made landfall or is crossing large landmasses such as the Philippines. However, the forecasters may ignore this rule for landfalling TCs on a case-by-case basis and discussion is being made in HKO about whether to allow the final T-number to decrease once the centre of the TC hits land.

4. CHANGES IN PROCEDURES OVER TIME

There has been little change to the procedures over the years.

5. DETERMINATION OF TC FINAL INTENSITY

In determining the final intensity of a TC, surface wind and pressure reports are regarded as ground truth but the quality of the observations are also taken into account (for example, pressure reported by ships can sometimes be suspicious). For TCs over the ocean where such observations are sparse, Dvorak analysis is used as the main tool for TC intensity determination. Other satellite intensity estimates, e.g. wind scatterometer, ADT, etc., are used as references.

Tropical cyclone's central pressure is estimated based on the surface pressure reported by land stations and ships, reconnaissance aircraft reports when available and Dvorak analysis via the wind-pressure conversion table.

The maximum surface mean wind speed is estimated based on the surface winds reported by land stations and ships, Doppler wind observations from radars, reconnaissance aircraft reports when available and Dvorak analysis. Estimates from wind scatterometer data, ADT, SATCON and the Multi-platform Tropical Cyclone Surface Wind Analysis by NOAA are also referenced.

6. INFLUENCES OF TECHNOLOGICAL ADVANCEMENTS ON DVORAK ANALYSIS

One notable influence is due to the advent of microwave imageries in recent years. Microwave imageries are less frequently available, but can serve as a supplement to Dvorak analysis. They enable the forecasters to see through clouds and view rainbands and eye of the TCs even when obscured by upper-level clouds, thereby helping to reveal the best pattern (e.g. banding versus shear or an eye pattern under a central cold cover) to use in the Dvorak classification. In addition, sea-level winds measured by QuikScat and ASCAT serve as a check on the location and strength of TCs.

7. ANCILLARY DATA CONSIDERED IN PRODUCING FINAL SATELLITE INTENSITY ESTIMATE

Since 2009, HKO has incorporated the "Advanced Dvorak Technique (ADT)" developed by the University of Wisconsin-Madison / Cooperative Institute for Meteorological Satellite Studies (CIMSS) as an objective reference tool for weather forecasters. ADT makes use of computer-based algorithms to objectively identify cloud pattern types, calculate the eye/convective cloud temperatures, apply selection rules, and derive intensity estimate for TC. One advantage of this tool is that it can be fully automated. The ADT is presently applied to the TC positions determined by the forecasters.

Scatterometer winds such as ASCAT or previously QuikScat, NOAA Multiplatform satellite surface wind analysis, images from microwave sensors available in the NRL website (http://www.nrlmry.navy.mil/TC.html), other resources from the web such as satellite-derived winds and dropwindsonde observations are also referenced by HKO forecasters.

8. PRESSURE WIND RELATIONSHIP IN USE

The empirical relationship between CI, the minimum sea level pressure (MSLP) for the Western North Pacific Basin and the 1-minute maximum mean wind speed (MWS) given in Dvorak (1984) is in operational use at HKO. A conversion factor of 0.9 is applied to convert the 1-minute mean winds to 10-minute mean winds. There have not been any changes regarding the above over the years, but HKO is currently considering adopting the new conversion factor of 0.93 as proposed in WMO/TD-No. 1555.

Conversion of the Dvorak CI number to MSLP and MWS

CI Number	MWS (10-minute mean in knots)	MSLP (hPa)
1.0	23	
1.5	23	
2.0	27	1000
2.5	31	997
3.0	41	991

3.5	49	984
4.0	59	976
4.5	69	966
5.0	81	954
5.5	92	941
6.0	103	927
6.5	114	914
7.0	126	898
7.5	139	879
8.0	153	858

9. SYSTEMS TO ENTER THE BEST TRACK RECORDS

Best tracking has been carried out by HKO officers who have rich experience in TC operation. The best tracks are determined independently from the operational environment. An advantage of best tracks over operational tracks is that the analyst can look back and forth to ensure a more reasonable and consistent track. References are also made to additional information such as tropical cyclone passage reports and best track data issued by RSMC Tokyo, which are not available operationally. Currently, there is no periodic re-visit of the best track record from previous years - this is only done on an ad-hoc and need-only basis.

The best track intensity will not normally differ too much from the warning intensity. Strong evidence is required for large changes in intensity.

DVORAK PROCESS IN JOINT TYPHOON WARNING CENTER

The Joint Typhoon Warning Center (JTWC) adheres to the following technical guidance when performing tropical cyclone analysis (positioning and intensity estimates):

- A Workbook on Tropical Clouds and Cloud Systems Observed in Satellite Imagery – Volume II – Tropical Cyclones, Dvorak, V. F. 1984 (NAVEDTRA 40971)
- Tropical Cyclone Intensity Analysis Using Satellite Data, Dvorak, V. F. (NOAA Technical Report NESDIS 11 – September 1984)
- The Dvorak Tropical Cyclone Intensity Estimate Technique, A Satellite-Based Method that Has Endured for over 30 years, Velden, et al, 2006 (BAMS, Vol 87 Issue 9, pp 1195 - 1210)
- Intensity Estimation of Tropical Cyclones During Extratropical Transition (JTWC/SATOPS/TN-97/002, Dennis Miller and Mark A. Lander, PhD, Apr 1997)
- A Satellite Classification Technique for Subtropical Cyclones, Herbert, P.J. & Poteat, K. O., 1975 (NOAA Technical Memorandum NWS SR-83 - 1975)

The following are local JTWC policies that are utilized with above guidance:

POLICY FOR PERFORMING DVORAK INTENSITY ESTIMATES OVER LAND

Satellite analysts will not perform Dvorak intensity estimates over large land masses such as Australia, China, India, Africa, and other mainland areas. These areas also include the larger islands in the area of responsibility, especially ones with mountainous topography, such as the Philippines, Taiwan, Mainland Japan, Sri Lanka, Madagascar, La Réunion, and the Hawaiian Islands.

The Dvorak intensity estimate should, however, be performed when possible. Performing a Dvorak intensity estimate over or near land will be a combined decision of the satellite analyst and the Typhoon Duty Officer (TDO) on duty. If the decision is to perform the estimate, then the following remark will be added to the remarks section of the Fix Entry Page. "Dvorak intensity may not be representative due to land influences."

If the satellite analyst does not perform an intensity estimate append the following remark to the remarks section of the Fix Entry Page. "Intensity estimate not performed due to systems proximity to land."

POLICY ON BREAKING CONSTRAINTS

While Dvorak constraints limit the amount of fix-to-fix variability due to rather short-lived fluctuations in system convection, it is sometimes necessary to break constraints to represent a rapidly developing or weakening trend. In this case, the analyst is encouraged to break constraints to provide the TDO and JTWC customers with the most accurate data possible. The analyst must provide sound reasoning for breaking constraints in the remarks section of the fix bulletin. The analyst must also consult with the TDO and contact Satellite Operations (SATOPS) leadership prior to deviating from the current Final-T by two T-numbers or more.

POLICY FOR UTILIZING SUBTROPICAL INTENSITY TECHINIQUE

A. SATOPs will use the subtropical technique of Hebert and Poteat (1975) to estimate the intensity of invest areas exhibiting the characteristics of a subtropical cyclone.

B. A subtropical cyclone is defined in the National Hurricane Operations Plan as "a non-frontal low pressure system that has characteristics of both tropical and extratropical cyclones. This system is typically an upper-level cold low with circulation extending to the surface layer and maximum sustained winds generally occurring at a radius of about 100 miles or more from the center."

According to Hebert and Poteat, the subtropical cyclone can originate from a decaying frontal wave, east of an upper trough, or from a cold low (TUTT cell.)

C. As defined by Hebert and Poteat, the criteria to classify a cyclone as "subtropical" include: main convection being located north and east of center position, cloud system size is at least 15 degrees latitude or more, and the convective cloud system should remain connected to other synoptic systems. The satellite analyst and TDO will collaborate to determine whether the system meets the aforementioned characteristics, and the system should be declared "SUBTROPICAL".

Note: additional data such as AMSU temperature cross-sections should also be examined, if available. After the subtropical determination has been made, the analyst will utilize the subtropical technique. The analyst will continue disseminating "subtropical" fixes until the system becomes tropical or extratropical in nature. Again, the TDO and SATOPS should collaborate to determine if/when the system has transitioned. At this point, all intensity estimates should be based on the traditional Dvorak or extratropical techniques.

MONSOON DEPRESSIONS

Assign an initial intensity of T0.0 since the Dvorak technique does not handle these systems well. These fixes will be position only and will not be transmitted. These fixes are typically only used within JTWC.

JTWC will continue assigning an intensity of T0.0 until Dvorak patterns and rules apply.